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Teaching Issues and Experiments in Ecology - Volume 13, November 2017

ISSUES : DATA SET

The Biology of Climate Change: The effects of a changing climate on migrating and over-wintering species at a high-elevation field station

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Far left: An undergraduate summer research student holds a yellow-bellied marmot that was trapped at RMBL. It is part of a population that has been studied continuously since 1962. Top right: billy barr prepares to ski to his weather monitoring station in the winter. Bottom right: A ruby-throated hummingbird visits scarlet gilia (Ipomopsis aggregata) near RMBL *(All photos courtesy RMBL).*

THE ECOLOGICAL QUESTION:

How does climate change affect the phenology of species in a high-elevation ecosystem? How might these changes in temperature and snow melt impact ecological interactions?

ECOLOGICAL CONTENT:

Climate change, environmental variation, phenology, species interactions, trophic mismatch

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WHAT STUDENTS DO:

Students engage with long-term environmental and phenology data sets (spanning over 40 years) collected at the Rocky Mountain Biological Laboratory, a high-elevation field station in Colorado, to explore the effects of climate change on the phenology of migrating and hibernating species. After becoming familiar with the geographic context, people involved with the data collection, and organisms studied through background readings and videos, students explore the raw data set in Excel or using an interactive data visualization tool. In small groups, students reproduce figures and regressions from Inouye et al. (2000) based on those data, then expand their analyses with data collected during the subsequent decade. By comparing analyses that encompass different time spans, students evaluate the original interpretations from Inouye et al. (2000), explain possible discrepancies, and generate predictions for future patterns. Finally, students build upon their initial analyses by developing and testing hypotheses about patterns found in other organisms in the data set, and combine these to discuss the ecological consequences of shifting plant and animal phenology in group presentations.

STUDENT-ACTIVE APPROACHES:

Cooperative learning, critical thinking, guided inquiry, jigsaw, open-ended inquiry, peer feedback

SKILLS:

- Interpret figures from the primary literature
- Use spreadsheets to organize, effectively visualize, and analyze data to evaluate predictions
- Construct and support an analysis of patterns in datasets
- Work collaboratively to develop hypotheses, interpret results, and present analyses
- Understand the biological impact of climatic variables on a single species, and how climate change affects interactions among species in complex ways

ASSESSABLE OUTCOMES:

- Short answers to reading questions that are completed as a pre-class assignment
- Reconstructed figures from a published dataset
- New figures from a larger dataset to test predictions
- Group presentations that include explanation of predictions, generation of a new figure from a large data set, regression analysis, and interpretation of the results
- Open-ended inquiry questions

SOURCES:

- The Biology of Climate Change from Digital RMBL. Available online at: http://www.digitalrmbl.org/case-studies/bcc_background/
- Inouye D.W., B. Barr, K.B. Armitage, and B.D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences 97: 1630-1633

OVERVIEW OF THE ECOLOGICAL BACKGROUND

The Rocky Mountain Biological Laboratory (RMBL) in Gothic, Colorado has maintained weather data and observations of the first sightings of migrating and hibernating species for over four decades. This work has received recent widespread press in the popular media, based on the award-winning video "The Snow Guardian". The climate and phenological data are compiled at digitalrmbl.org, as raw data, in an interactive data-visualizer, and summarized in several published papers that show the effects of global and local climate change on phenology. In this module, students explore patterns within the phenological and climate data from 1975-2010 to test predictions about the effects of climate change on the phenology of migrating and hibernating species at RMBL. After becoming familiar with the geographic context, people involved with the data collection, and organisms studied through background readings and videos, students explore the raw data set in Excel or using an interactive data visualization tool. In small groups, students reproduce figures and regressions from Inouye et al. (2000) based on those data, then expand their analyses with data collected during the subsequent decade. By comparing analyses that encompass different time spans, students evaluate the original interpretations from Inouye et al. (2000), explain possible discrepancies, and generate predictions for future patterns. Finally, students build upon their initial analyses by developing and testing hypotheses about patterns found in other organisms in the data set, and combine these to discuss the ecological consequences of shifting plant and animal phenology in group presentations.

DATA SETS

Three data sets are used in this activity.

- *Data set used in Inouye et al. 2000:*
  Inouye_2000_PNAS_Data_sightings.xlsx

- *Updated phenology data set from 2000 to 2010:*
  RMBL_phenology_2000to2010.xlsx

- *Complete climatic data set from Sept. 1975 to July 2010, including daily minimum and maximum temperature, new snow, melt water equivalent, total snowfall, snow pack, and rainfall:*
  RMBLWeatherData_Sept1975toJuly2010.xls

The original data file provided by David Inouye and colleagues is also available for instructors to use. It is provided in the format in which it was received:
Inouye_2000_PNAS_Data.xlsx

Instructors may wish to use this file in a supplementary activity to discuss best practices for formatting data files. Additional worksheets in this file also illustrate alternative ways in which Inouye and colleagues explored their data.

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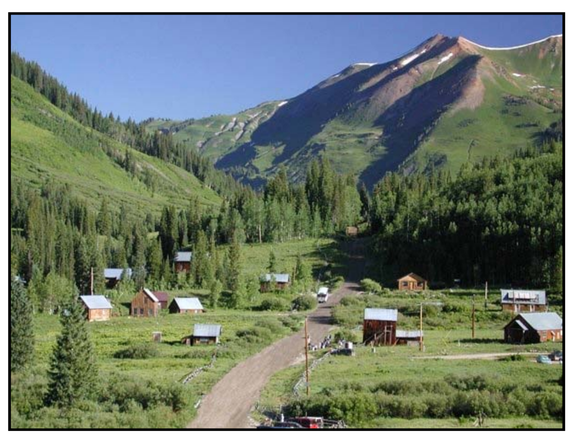
STUDENT INSTRUCTIONS

Digital RMBL:
Effects of rapid climate change on phenology at high altitudes

Virtually all species use predictable yearly changes in their local climate to determine when to initiate life-cycle events like breeding, flowering, and migration. Environmental factors such as temperature, day length, and precipitation can directly control the timing of these biological events, or act as cues that set an organism's "biological clock" (Forrest and Miller-Rushing 2010). Over the past two decades, a growing body of evidence suggests that climate change is affecting this seasonal timing, or **phenology**, of plants and animals in a wide range of ecosystems, including temperate forests (Both et al. 2009), freshwater lakes (Seebens et al. 2009), and the open ocean (Koeller et al. 2009). While these shifts in an organism's life-history timing may keep it well-synchronized with local environmental changes, its interactions with other species may be disrupted. This **tropic mismatch**, or decoupling of interacting species, can result if the species do not show the same phenological shifts in response to a changing environment. For example, as the initiation plant growth has advanced in response to warming spring temperatures, peak food availability no longer corresponds to the timing of caribou reproduction, resulting in fewer births and more deaths among caribou calves in Greenland (Post and Forchhammer 2008). This trophic mismatch results from species using different environmental signals to regulate their phenology: the caribou are cued by increasing day length to migrate to areas where newly-emergent food should be plentiful, but plants initiate growth in response to temperature, not day-length.

In the following case study, you will explore a long-term data set of climatic variables and phenology that have been collected at the Rocky Mountain Biological Laboratory (RMBL) in Gothic, Colorado for several decades. Since the mid-1970s, long-term resident and RMBL accountant, billy barr (he does not capitalize his name), has been recording weather conditions and the date of first sightings of many animal and plant species following snow melt. These data provide a unique opportunity to look for trends in phenology as they relate to climatic conditions.



Above: *The Rocky Mountain Biological Laboratory, founded in 1928, is located at 9800 ft. elevation in Gothic, CO.*

With your classmates, you will evaluate the data from RMBL that formed the foundation of a study by Inouye et al. (2000), and then examine whether trends identified during that time period are supported by an additional 10 years of data collected during the subsequent decade.

The broader goals of this activity are to help you strengthen skills in:

- evaluating scientific figures
- understanding statistical significance and regression
- creating effective visual presentations (i.e., graphs) using Excel
- testing a hypothesis with a long-term dataset

To be completed prior to lab

- Read the article "The Hermit Who Inadvertently Shaped Climate-Change Science" from *The Atlantic*, which introduces you to billy barr and why he started collecting these data in the first place:

  https://www.theatlantic.com/science/archive/2017/01/billy-barr-climate-change/512198/

- Read the article by David Inouye and colleagues upon which this activity is based, and respond to the following questions.

  Inouye D.W., B. Barr, K.B. Armitage, and B.D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences 97: 1630-1633.

Pre-lab questions:

1. Numerous scientists have determined that the growing season is starting earlier at lower elevations. What did Inouye and colleagues determine was happening to the start of the growing season in the high Rockies around RMBL from the 1970s through the 1990s? Provide support for your response from Inouye *et al*. (2000).

2. How, if at all, do you think what Inouye observed might affect migrating species that visit the high Rockies in the summer? What about hibernating resident species?

Far left: *An undergraduate summer research student holds a yellow-bellied marmot that was trapped at RMBL. It is part of a population that has been studied continuously since 1962.* ***Top right:*** *billy barr prepares to ski to his weather monitoring station in the winter.* ***Bottom right:*** *A ruby-throated hummingbird visits scarlet gilia* (Ipomopsis aggregata) *near RMBL (All photos courtesy RMBL).*

<u>In-class instructions</u>

Over a decade has passed since David Inouye and colleagues published their paper in 2000. billy barr continues to collect daily weather data and record the first spring sightings of many migrating birds, hibernating mammals, and spring flowers. This ongoing data set provides the opportunity to explore the relationships between climate and phenology across an even broader timeframe, and to compare short and longer-term trends.

To provide context for where these data were collected, at the start of the class period, we will first watch the following two short videos. As you watch them, take notes, and be prepared to share at least two ideas/impressions/questions that came to mind, which can relate back to the paper by David Inouye, billy barr, and colleagues:

> **Video:** *The Snow Guardian*
> https://vimeo.com/182392548

Overview:
To provide yourself with a framework for this activity, follow the link below to access the background for the Biology of Climate Change module from Digital RMBL:

> http://www.digitalrmbl.org/case-studies/bcc_background/

Read through the first two pages of the module: **Introduction** and **RMBL Phenology**. When you are finished, watch the following video to see how much snow actually falls in this area, based on a time-lapse of photos from the RMBL permanent weather station at the peak of nearby Snodgrass Mountain:

> **Video:** Time lapse of snow pack at Snodgrass Mountain, CO
> https://www.youtube.com/watch?v=LCcbWK3UAUE&feature=youtu.be
>
> *Helpful hint: If you want to watch the change in the snow level more closely, you can slow down the speed using the YouTube settings.*

When all students are done reading through the background, we will touch base to strategize for the rest of the lab period.

Data sets:
You will need to download three data sets to use for this assignment.

- *Data set used in Inouye et al. (2000), from 1975 to 1999:*
  Inouye_2000_PNAS_Data_sightings.xlsx

- *Updated phenology data set from 2000 to 2010:*
  RMBL_phenology_2000to2010.xlxs

- *Complete climatic data set from Sept. 1975 to July 2010, including daily minimum and maximum temperature, new snow, melt water equivalent, total snow fall, snow pack, and rainfall (note that this is a large Excel file, and may be slow to download).*
  RMBLWeatherData_Sept1975toJuly2010.xls

Part 1. Working with large data sets from the primary literature

To familiarize yourself with managing large spreadsheets of data, you've been provided with the raw data used by Inouye and colleagues for their analysis in the 2000 study (Inouye_2000_PNAS_Data_sightings.xlsx). For this lab activity, you will use data in the worksheet called "First Sightings Data."

The "First Sightings Data" worksheet tab contains both climatic and phenological data. The three climate variables (Snow Melt Date, Total Annual Snowfall, and Average Snowpack) have "C-" at the start of their names. The date of first observation for 22 organisms are also included: two hibernating animals ("H-"), 17 migratory animals ("M-"), and three plants ("P-"). Those species are also listed in **Table 1** on this handout, which includes both the scientific and common name for each organism.

Table 1: Plant and animal species whose phenology has been monitored at the RMBL. Data for these organisms are included in the "First sightings data" worksheet tab of the Excel file *Inouye_2000_PNAS_Data_sightings.xls*

Scientific name	**Common name**
Marmota flaviventris	Yellow-bellied marmot
Tamias minimus	Least chipmunk
Turdus migratorius	American robin
Cyanocitta stelleri	Steller's jay
Agelaius phoeniceus	Red-winged blackbird
Junco hyemalis	Dark-eyed junco
Colaptes auratus	Northern flicker
Tachycineta bicolor	Tree swallow
Sphyrapicus nuchalis	Red-naped sapsucker
Passerella iliaca	Fox sparrow
Regulus calendula	Ruby-crowned kinglet
Setophaga coronata	Yellow-rumped warbler
Petrochelidon pyrrhonota	Cliff swallow
Callospermophilus lateralis	Golden-mantled ground squirrel
Selasporus platycercus	Broad-tailed hummingbird
Zonotrichia leucophrys	White-crowned sparrow
Molothrus ater	Brown-headed cowbird
Sialia currucoides	Mountain bluebird
Setophaga petechia	Yellow warbler
Mertensia ciliata	Tall-fringed bluebell
Erythronium grandiflorum	Glacier lily
Claytonia lanceolata	Western spring beauty

The snow melt date and phenology data are recorded in terms of JD, or Julian day. This simply indicates the day of year, where Day 1 = January 1, Day 32 = February 1, and so on. Notice that these column headers indicate the units of measurement in parentheses after the variable name, as "(JD)". Including the unit of measurement when recording data is a very important habit to get into! Also note that cells in the spreadsheet that contain a period, or " . " indicate that no data are available for that entry.

A. **Reproduce three plots** (Figures 1, 3, and 4), from Inouye et al. (2000) using Excel. Remember that the data used for this study are found here: Inouye_2000_PNAS_Data_sightings.xlsx

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Figure 1. Winter snowfall at RMBL from 1975 to 1999.
Figure 3. Date of the first sighting of a robin at RMBL from 1974 to 1999.
Figure 4. Date of the first sighting of a marmot at RMBL from 1976 to 1999.

For each of the relationships depicted in those three figures, determine:

- What is the rate of change per year? (*Hint*: include the units in your response)
- Is this rate of change significantly different from zero? What supports your conclusion?
- Do you see similar trends across all three relationships? If not, how do they differ?

B. **Have these trends held over the longer term?** Your group will now re-examine one of those three sets of variables (from Figure 1, 3, or 4), but across a different time frame than what Inouye and colleagues used, to determine if the trends they observed have held up in subsequent years. We will consider two new time frames:

- An extended data set (1975-2010)
- Just the most recent decade (2000-2010)

Your group will be responsible for examining one variable (from either Figure 1, 3, or 4) across one of these new timeframes (1975-2010, or 2000-2010). **Your instructor will tell you which variable + timeframe combination to focus on, so be sure you know this before moving on!**

For this analysis, will need to retrieve data from the most recent decade from this data file: RMBL_phenology_2000to2010.xlsx. That file contains records for the same variables as in Inouye_2000_PNAS_Data_sightings.xls but for a different timeframe. To work with the extended data set, you simply need to merge the data from the two files into a single spreadsheet. *Hint: be sure the columns are in the same order when you merge the files!*

For your focal time frame and variable,

- Generate a new scatter plot for the same relationship as in the figure published by Inouye and colleagues.
- Fit a new regression line to the timeframe you are examining.
- Calculate descriptive statistics for your response variable (mean, minimum, and maximum).
- For your organism (American robin if you're working with Figure 3, or yellow-bellied marmot for Figure 4), how much would its date of first emergence/sighting shift with a 2-day earlier snowmelt date?

Hint: consider how you will need to change your analysis to answer this question.

- Decide whether the trends you've found are consistent with those presented in Inouye *et al.* (2000) for the same variable.

As a whole class, we will generate a total of six new figures to cover all combinations of variables and time frames. Before moving on, be sure that all members of your group have a copy of your analyses up to this point.

Part 2: How do patterns in the data vary with time?

- Describe how the new plots you made in Part 1B differ from the original plots (in Inouye et al. 2000). Do the original plots support the original interpretations? Justify your reasoning. Do the updated plots suggest new interpretations? How have abiotic conditions changed over the extended period of record? How do phenological phenomena change with the extended record? What are your predictions for future change?

- Next, pair with another team who analyzed the same relationship (that is, the same set of variables), but for a different timeframe. In combination with the analysis from Inouye *et al*. (2000), you should now have three timeframes (1974-1999, 2000-2010, and 1974-2010) over which the same relationship was evaluated. Compare your results! Do your analyses show the same trends? Do they differ? What might explain these similarities or deviations between timeframes? What do you think of the conclusions drawn by Inouye and colleagues, based on this additional data? Be prepared to present your results to the rest of the class.

Part 3: Generate and test a new hypothesis using the climate and phenology data

- With your understanding of phenology and a few important RMBL datasets, here's your chance to ask and answer your own questions.

    - Frame a question that you think you can answer using the data set that extends through 2010. If you wish, you can explore the truncated data (through 2000) using the data visualizer tool through DigitalRMBL (http://www.digitalrmbl.org/case-studies/bcc_datavisualizer/). It's really cool, but be aware that this program can be finicky, so don't get too frustrated if it doesn't work on your computer.

    - If not done so already, consider downloading billy barr's updated climate data that extends through 2010: RMBLWeatherData_Sept1975toJuly2010.xls

This larger file contains daily records for the following environmental variables:

Min temp (°C)	max temp (°C)	new snow (cm)
melt water (in)	melt water (cm)	total snow (cm)
snow pack (cm)	rainfall (in)	rainfall (mm)

Helpful hint: Notice that this file contains daily values, rather than monthly or annual values. You may need to calculate averages or sums to generate the variables needed to address your questions.

- Generate one or more graphs (and perhaps some statistics!) to test your hypothesis and support your interpretations.

- **Important details!**
  - **Each group must have their study question approved by the instructor before leaving the class today!**

  - Each group will need to prepare a 3-slide presentation that will be presented during the subsequent class:
    - Slide 1: organism information, including photo, something interesting/surprising about the organism's biology and justification for your group's prediction
    - Slide 2: Figure illustrating the patterns observed in the data
    - Slide 3: Analysis/conclusions in approx. 3 bullet points

  - The 3-slide presentation must be emailed to your instructor no later than **1 hour before the start of our next class**, and must be sent as a **.pdf file**, so that it can be loaded onto a classroom computer. Saving it as a .pdf, instead of .ppt or .key or whatever other presentation software you're using prevents formatting errors between operating systems, and also prevents the use of extraneous slide transitions and animations.

Literature cited

Both C, M van Asch, RG Bijlsma, AB van den Burg, and ME Visser. 2009. Climate change and unequal phenological changes across four trophic levels: constraints or adaptations? Journal of Animal Ecology, 78, 73-83.

Forrest J and AJ Miller-Rushing. 2010. Toward a synthetic understanding of the role of phenology in ecology and evolution. Philosophical Transactions of the Royal Society B 365: 3101–3112.

Koeller P, C Fuentes-Yaco, T Platt, S Sathyendranath, A Richards, P Ouellet, D Orr, U Skúladóttir, K Wieland, L Savard, and M Aschan. 2009. Basin-scale coherence in phenology of shrimps and phytoplankton in the North Atlantic Ocean. Science 324: 791- 793.

Inouye DW, B Barr, KB Armitage, and BD Inouye. 2010. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences 97: 1630-1633.

Post E and MC Forchhammer. 2008. Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. Philosophical Transactions of the Royal Society B 363: 2369–2375.

Seebens H, U Einsle, and D Straile. 2009. Copepod life cycle adaptations and success in response to phytoplankton spring bloom phenology. Global Change Biology 15: 1394- 1404.

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NOTES TO FACULTY

1. **Preparation before lab**
   a. Provide background lecture about phenology, species interactions, climate sensitivity, or other topics as pertinent to your course (for example, I've used this in a class on biological invasions, so contextualized this module with how the success of biological invasions depends in part on interactions between species, which can be moderated by their physical environment)
   b. Review basics of graphing, figure formatting, and regression analysis as needed. The data analysis in this lab requires basic graph-building skills, as well as familiarity with simple linear regression. Depending on the background of the students, it would be helpful for instructors to introduce/revisit basic figure-formatting essentials, including: Independent vs. dependent variables (and which axis they correspond to); labeling axes (variable name and units, with appropriate scales); line graphs vs. scatter plots; and figure legend contents. Also consider a quick refresher on the basics of linear regression, the formula for the best fit line, and how to use the slope as an indicator of rate of change.
      i. For a brief overview of descriptive statistics and regression analysis that uses the data from this study, students can be referred to the "A Bit About Statistics" page: http://www.digitalrmbl.org/case-studies/bcc_stats/

   c. Remind students to print out / download the lab handout, read through it, and complete the "prelab" activities prior to lab:
      i. Background information about the location (Rocky Mountain Biological Laboratory, Gothic, CO) and people (billy barr, RMBL accountant) involved in the data set:

         Article from *The Atlantic*:
         https://www.theatlantic.com/science/archive/2017/01/billy-barr-climate-change/512198/

         Video: *The Snow Guardian*
         https://vimeo.com/182392548

         Video: Time lapse of snow pack near RMBL
         https://www.youtube.com/watch?v=LCcbWK3UAUE&feature=youtu.be
         Note: The video "The Snow Guardian" can be viewed at the start of the lab period, to help students become focused on the activity. Run time: 4 min. 53 sec.

ii. Read the article upon which this activity is based, and complete the initial questions for consideration:

Inouye D.W., B. Barr, K.B. Armitage, and B.D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences 97: 1630-1633.

Note: Depending on your students, these pre-lab questions can be collected at the start of lab, graded for completion/accuracy, or used for a think-pair-share discussion at the start of lab, before students begin working with the data.

2. **During lab time (3 hours)**
   a. (Re) watch the video, The Snow Guardian (4min 53 sec)
   b. Before beginning the activity,
      i. Guide a short discussion about the overall conclusions and predictions drawn from Inouye et al. (2000), using think-pair-share or similar approach
      ii. If desired, remind the students of tutorials available for using Excel and conducting linear regression (I've made these for Excel and JMP, depending on the course)
   c. Active learning (allow about 2.5 hours)
      i. After reading through the background information on the digitalRMBL site, you may choose to have students use interactive Google Motion Data Visualizer tool (http://www.digitalrmbl.org/case-studies/bcc_datavisualizer/) to visually explore their data for patterns or trends. This is optional, and some colleagues have reported difficulty getting the tool to work on their computer. It is not necessary to use this to complete the activity. You may consider getting this to work on a classroom computer and projecting it for the class.
      ii. **During Part 1:**
         1. Remind students to use the published figures from Inouye et al. (2000) as stylistic models
         2. **For Section A** (reproducing plots from the paper):
            a. This is intended to get students familiar with Excel and seeing patterns in data.

b. The data set provided for the students to work with is in a file called Inouye_2000_PNAS_Data_sightings.xlsx
c. Note that the raw data set that was provided by the study's authors (Inouye_2000_PNAS_Data.xlsx) contains additional tabs than what the student need for this activity. Those sheets show ways in which they further explored the data, but are not particularly well-formatted. You may wish to either (1) just give the students the Excel file that simply contains the first sheet (this is the file called Inouye_2000_PNAS_Data_sightings.xlsx), or (2) give them the complete file, and use it as a point of discussion.
d. Consider grouping students with mixed familiarity with Excel and data analysis, if needed. Working in pairs or small groups will enable students to help each other with the nitty-gritty of using the software. Further, this can help boost confidence in analyzing data and presenting it to the class, rather than doing so individually.
e. Students may need guidance when addressing the question in Part 1A (second bullet) that asks whether the rate of change is significantly different from zero. I consider this a "challenge question" because some students find it challenging to think about how to apply statistical analyses to their biological questions. Here, they need to conduct a regression analysis and statistically test whether the slope is different from zero.
f. These can be smaller groups (pairs) that differ from the groups in section 2, if you would like students to experience working with different partners.
g. Note that Figure 3 from Inouye et al. (2000) has two regressions, which address different time frames in the original data set. Depending on the background of your students, you can have them just construct one regression, or try

to reproduce both. This can be a good discussion segue into how "cherry picking" can lead to different interpretations from the same overall data set.

h. If time permits, consider having teams exchange their reproductions of the Inouye et al. (2000) figures, to provide peer feedback on whether the reproductions are formatted correctly. This can be non-graded, but provide timely feedback that will inform the subsequent figure productions. This can take ~5-10 minutes, allowing for a brief, all-class final discussion on good and weak things observed.

3. For **Section B (have trends held over the longer term?):**
   a. Divide students into at least six teams to work with the extended data set. Duplicate teams may be needed for large classes, but at least six groups are needed to cover all iterations of 3 figures and two timeframes.
   b. After student groups have generated their figure (this should go more quickly than Section 1, since each group only generates a single figure), have students write their response on the board as to whether the trends from Inouye et al. (2000) have held up over the longer term. This can be a simple "Yes" or "No", or with statistical support, depending on the sophistication of the class.

iii. During **Part 2 (comparing plots that use different time frames):**
   1. Using a Pairs-Share type approach, have teams who have analyzed the same variables, but in different timeframes, pair together to compare their graphical and statistical results. Consider why the timeframes (1974-2000, 2000-2010, and 1974-2010) might show different patterns.
   2. Depending on time available and computer savvy of the students, the follow-up discussion can take different formats. You could have a similar "Yes" vs "No" table to fill out on the board as in Section B, or you could have students make a single Powerpoint

slide with three panels on it, showing the regression for the three timeframes side by side.

3. In whole-class discussion, have the larger groups report back to the class, and determine if patterns hold across the variables examined. As needed, guide the discussion to help students consider how trends may change across timeframes, and why different organisms might respond differently to environmental change (e.g. slower rates of evolutionary response due to lifespans, differing dependency on a particular variable, migratory vs. resident organisms). This discussion can help students begin to formulate ideas for their independent hypotheses in Part 3.

iv. During **Part 3 (Open ended inquiry):**

1. Encourage students to look up information about multiple organisms before choosing their focal system. Requiring instructor approval before students complete the remainder of the activity allows you to ensure the student teams work on unique questions. Some students may need additional guidance when trying to construct questions that can actually be answered with the data set provided. I'd suggest emphasizing not having "year" on the x-axis, but instead have students explore how phenology changes with a potential abiotic cue. It can be helpful to remind students that the x-axis shows the (potential) explanatory variable. If they them write a hypothesis to test that asks how the phenology changes with a particular abiotic variable, then that variable should be on the x-axis, rather than year.
2. With advanced classes, consider having teams look at patterns beyond a single species, or examine more complex patterns that require calculating new variables from the climatic data provided. For example, do all resident rodents show the same relationship to changes in snow melt date? Has the length of growing season changed at RMBL over the past decade? Has the timing of first sighting for migratory birds or hibernating animals changed since Inouye's research was published?

v. Before leaving the lab period, the instructor can choose to have students turn in electronic or hard-copies of their original figures, to receive individual assessment.

d. Reminders for homework requirements
    i. As needed, remind students about best practices for slide presentations (One prompt I've used is to have small groups brainstorm effective and not-so-effective things they've seen in other class presentations (by instructors or students), and then have one "reporter" from each group write two items from each category on the board. This usually initiates a lively and useful discussion.)

3. **Post-lab**
    a. Student groups complete their analyses based on the organisms their group chose, and prepare a 3-slide presentation for the subsequent class or lab meeting:
        i. Slide 1: organism information, including photo, something interesting/surprising about the organism's biology and justification for their group's prediction
        ii. Slide 2: Figure illustrating the patterns observed in the data
        iii. Slide 3: Analysis/conclusions in approx. 3 bullet points
    b. If desired, consider an open-ended discussion about the following themes (which may be distributed to students at the start of this second meeting, or after the presentations):
        i. **Comparing across the class examples:** Do all species exhibit identical shifts in emergence with an increase in temperature, or do some species show greater changes than others as temperature increases? Support your response with specific examples.
        ii. **Scientific vs. popular media:** How is evidence for climate change portrayed in these two different genres?
        iii. **What is long-term data?** billy barr's dataset contains nearly 40 years of data. Do you consider this a long-term data set? What is a long-term data set? Why might they be difficult to come by? What considerations do you think need to be made when extrapolating from long (or not-so-long)-term datasets?
    c. Please feel free to revise the out-of-class assignment as appropriate for your classroom. The student instructions are written to preempt some potential challenges that I've encountered with other group-based presentations (file formatting, specifics on slide design, etc.). Also, remember that the optional data file provided by

David Inouye (Inouye_2000_PNAS_Data.xlsx) contains additional worksheets with data used throughout the rest of the paper, should you wish to explore further additional analyses used in their study. Have fun with the presentations!

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